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STREAMLINING THE WALLS OF AN EMPTY
TWO-DIMENSIONAL FLEXIBLE-WALLED TEST SECTION

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16. Abstract

This is a progress report on work undertaken on NASA Grant NSG-7172 entitled "The Self Streamlining of the Test Section of a Transonic Wind Tunnel." The Principle Investigator is Dr. M. J. Goodyer. The report outlines the techniques and streamlining methods used, results, and conclusions from an extensive series of tests aimed at closely defining sets of "aerodynamically straight" walls for the Transonic Self-Streamlining Wind Tunnel.

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1. Introduction

The streamlining of an impervious flexible test section wall around a model relies on the computation of a flowfield imagined to pass over the outside of the flexible wall and extending to infinity[1]. Perturbation of the imaginary flowfield depend on the displacement of the wall from straight, and this raises the issue of what constitutes a "straight" wall. The policy has been adopted of calculating the general displacement of a wall by referencing it to an "aerodynamically straight" contour which has been found to give a constant Mach number along the empty test section equal to, within close tolerances, the tunnel reference Mach number. This report outlines the techniques and streamlining methods used, results, and conclusions from an extensive series of tests aimed at closely defining sets of "aerodynamically straight" walls for the Transonic Self-Streamlining Wind Tunnel (TSWT)[1].

2. Experimental Technique

The TSWT test section is a nominal six inches square in cross section and has flexible top and bottom walls 44 inches long, each fitted with 20 motorised screw-jacks. The sidewalls are rigid and non porous. Static pressures are measured on the centreline at the first 18 jacks on each flexible wall, allowing the local Mach number to be calculated and adjusted by means of jack movement. The test section is sketched on figure 1. The tunnel is closed circuit with induced drive, using dried air at atmospheric stagnation conditions in the test section. The tunnel reference Mach number is derived from the settling chamber stagnation pressure and the centre-sidewall reference static orifice positioned level with the beginning of the flexible walls as shown on figure 1.

As a convenient starting point the flexible walls were set to geometrically straight contours, parallel to each other and to the pair of test section backbones to which the jacks were attached. Of course when run in this condition the Mach number distributions along the flexible walls were non uniform because of the growth of the wall boundary layers.

The aim was to diverge the two flexible walls by roughly equal amounts necessary to absorb the growth of displacement thickness on all four walls.

The divergence is presumably a function of the Reynolds number and Mach number. In this tunnel the two vary together because of the nominally fixed stagnation conditions and therefore it is necessary only to vary and control one, Mach number for convenience. However, in tunnels which have provision for the variation of stagnation temperature and/or pressure, the determination of "aerodynamically straight" walls will presumably be a more complex procedure.

The variation of aerodynamically straight wall contours is in principle a continuous function of, in the case of this wind tunnel, test Mach number. In the streamlining of the walls around a model at a particular reference Mach number, wall displacements can be referenced to the aerodynamically straight contours for the same Mach number. In principle the aerodynamically straight contours can be determined experimentally over a range of Mach number and the contours appropriate for a model test be determined by interpolation. However, in practice, it has been found that the variations of wall contours are a rather weak function of Mach number and it is adequate to determine only a few such aerodynamically straight contours and to designate each as the aerodynamically straight contour for a band of reference Mach numbers. Table 1 below shows the nominal Mach numbers at which aerodynamically straight walls were determined, and the bands of Mach number over which they are judged valid.

3. Streamlining method

The normal streamlining of flexible walls around a model is carried out using a well known predictive method[2] which in practice often drives the walls to streamlines in one adjustment. However the method was not directly applicable to the task under discussion here, and attempts to use it were not practical. As an alternate an old streamlining method[3] was reinvoked. This old method simply uses the rule that, in subsonic flow, the Mach number at a point on a wall will be reduced by moving the wall locally away from the test section centreline, and vice-versa. The relationship between the wall movement δy and desired change of Mach number δM which worked satisfactorily with this test section was simply $\frac{\delta y}{\delta M}$ = 0.4 to 0.5 inches. Position setting accuracy is estimated to be $\pm$ .076 mm (.003 inch).

4. Results

Aerodynamically straight contours (which are stored as a set of readings of the jack position transducers) were routinely determined at reference Mach numbers of 0.7, 0.8 and 0.85, contours A, B and C respectively. Streamlining wall adjustments were continued until variations in the wall Mach numbers were small. The standard deviation σ of the Mach number errors between 18 measuring points on each wall and the reference Mach number were then computed, typically lying in the band 0.002 to 0.005. The A Contours are used as the aerodynamically straight reference contours for all reference Mach numbers M_∞ up to 0.725 (See figure 2.1). Table 1 shows σ after streamlining at $M_\infty = 0.7$ and also for the same contours at $M_\infty = 0.3$, 0.5, 0.6 and 0.725. The B Contours cover the Mach band 0.725 to 0.825 (See figure 2.2) and the C Contours the band 0.825 to 0.90 (See figure 2.3).

Figure 2 indicates where an airfoil model of typical chord size would be positioned relative to the test section. Of course no model was present during these tests.

The standard deviations tend to rise with Mach number. A weighting would be appropriate, and the one chosen here for convenience is σ/M_∞ shown in Table 1.

The consequence of running one of the contours at a Mach number outside its designated band of validity is not serious. For example the B contours when run at Mach 0.85 showed a standard deviation of roughly 0.004.

The errors revealed in table 1 and on figures 2 are thought to be quite acceptable for immediate purposes, showing that the tunnel and its computer control have adequate precision. The contours are used when necessary as a starting point for streamlining with a model present.

It is expected that the control of Mach number with an empty test section will become rapidly more difficult as Mach 1 is approached. Serious attempts have not yet been made at determining aerodynamically straight contours applicable to Mach numbers above 0.9, although non-uniform flow in the Mach band 1.0 to 1.05 has been established along the entire length of the test section.

5. Conclusions

1. Aerodynamically straight wall contours can be easily found experimentally.

2. Three aerodynamically straight wall contours are sufficient to cover testing up to Mach 0.9.

3. The wall setting accuracy of $\pm$.0762 mm ($\pm$.003 inch) is sufficient to achieve acceptable local wall Mach number distributions over the test Mach number range up to 0.9.

4. Further work is necessary to define aerodynamically straight walls above Mach 0.9.

6. References

1. Goodyer, M.J., Wolf, S.W.D.
'The Development of a Self-Streamlining Flexible Walled Transonic Test Section'.
AIAA Paper 80-0440, March 1980

2. Judd, M., Wolf, S.W.D., Goodyer, M.J.,
'Analytical Work in Support of the Design and Operation of Two-Dimensional Self-Streamlining Test Sections'.
NASA CR-145019, July, 1976

3. Goodyer, M.J.,
'The Self-Streamlining Wind Tunnel'
NASA TM X-72699, August, 1975

Table 1

Performance of Aerodynamically Straight Walls - Empty test section

Contours	Mach no. at which contours were determined experimentally	Mach band of validity		Measured Standard deviation of local Mach number		Weighted deviation: Average σ/M_∞
			M_∞	Top wall σ	Bottom wall σ	
A	0.7	0.3 to 0.725	0.3 0.5 0.6 0.7 0.725	.0010 .0012 .0011 .0021 .0018	.0014 .0014 .0020 .0023 .0030	.004 .0026 .0026 .0031 .0033
B	0.8	0.725 to 0.825	0.725 0.75 0.8 0.825	.0033 .0017 .0023 .0047	.0030 .0024 .0027 .0043	.0043 .0027 .0031 .0055
C	0.85	0.825 to 0.9	0.825 0.85 0.9	.0031 .0031 .0036	.0030 .0033 .0032	.0037 .0038 .0038

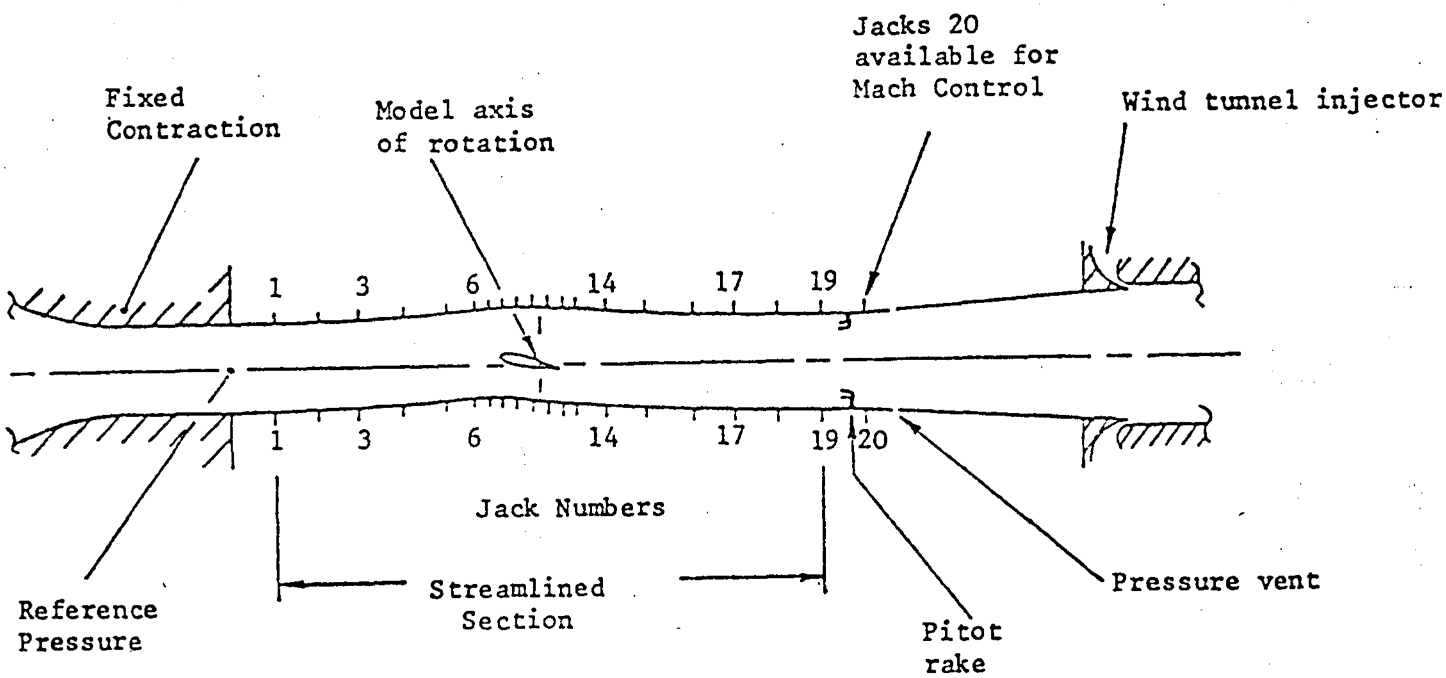

Fig 1. Transonic flexible walled test section layout

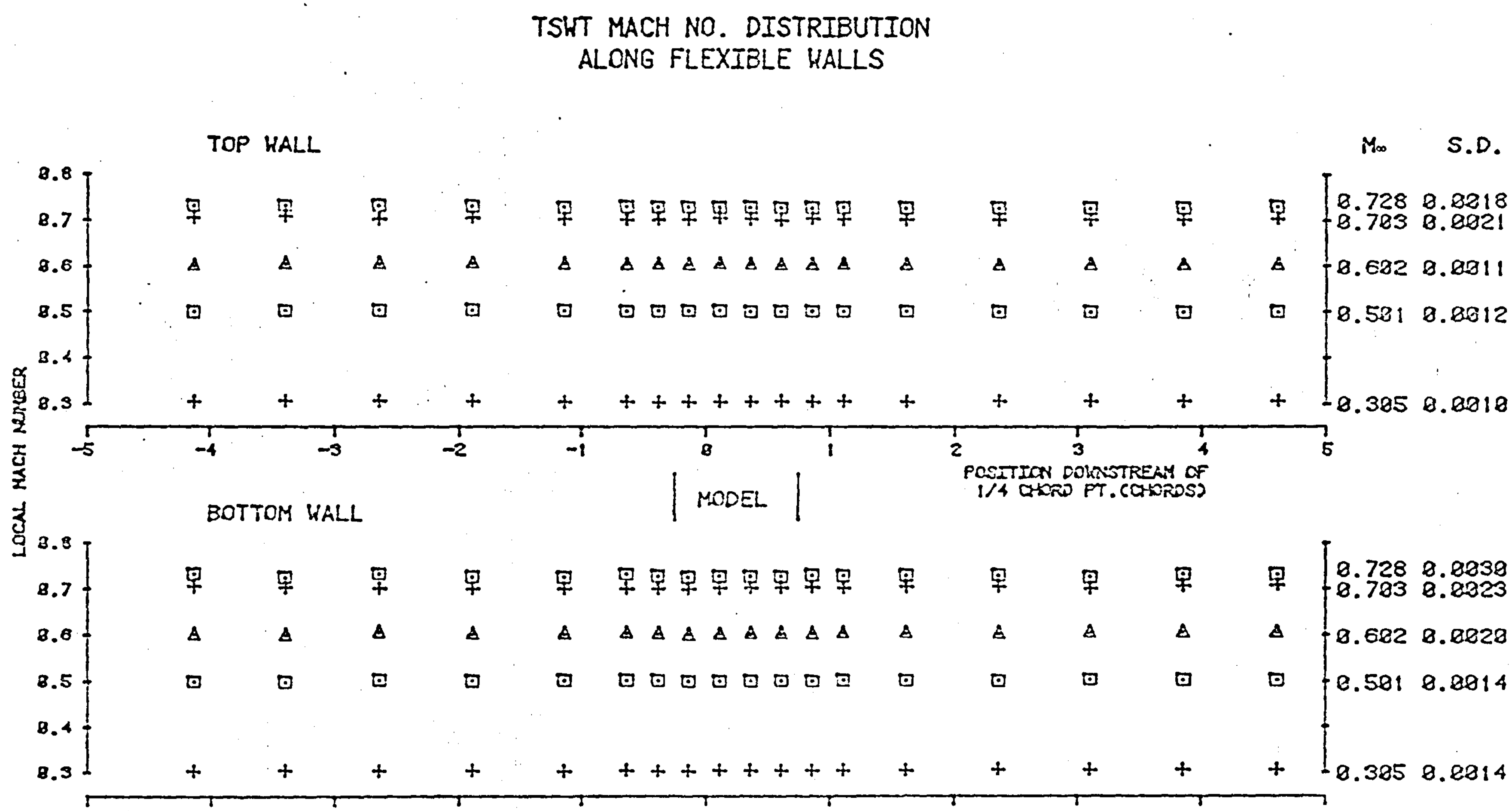

Fig 2.1 Test section wall Mach number distributions, aerodynamically straight contours A

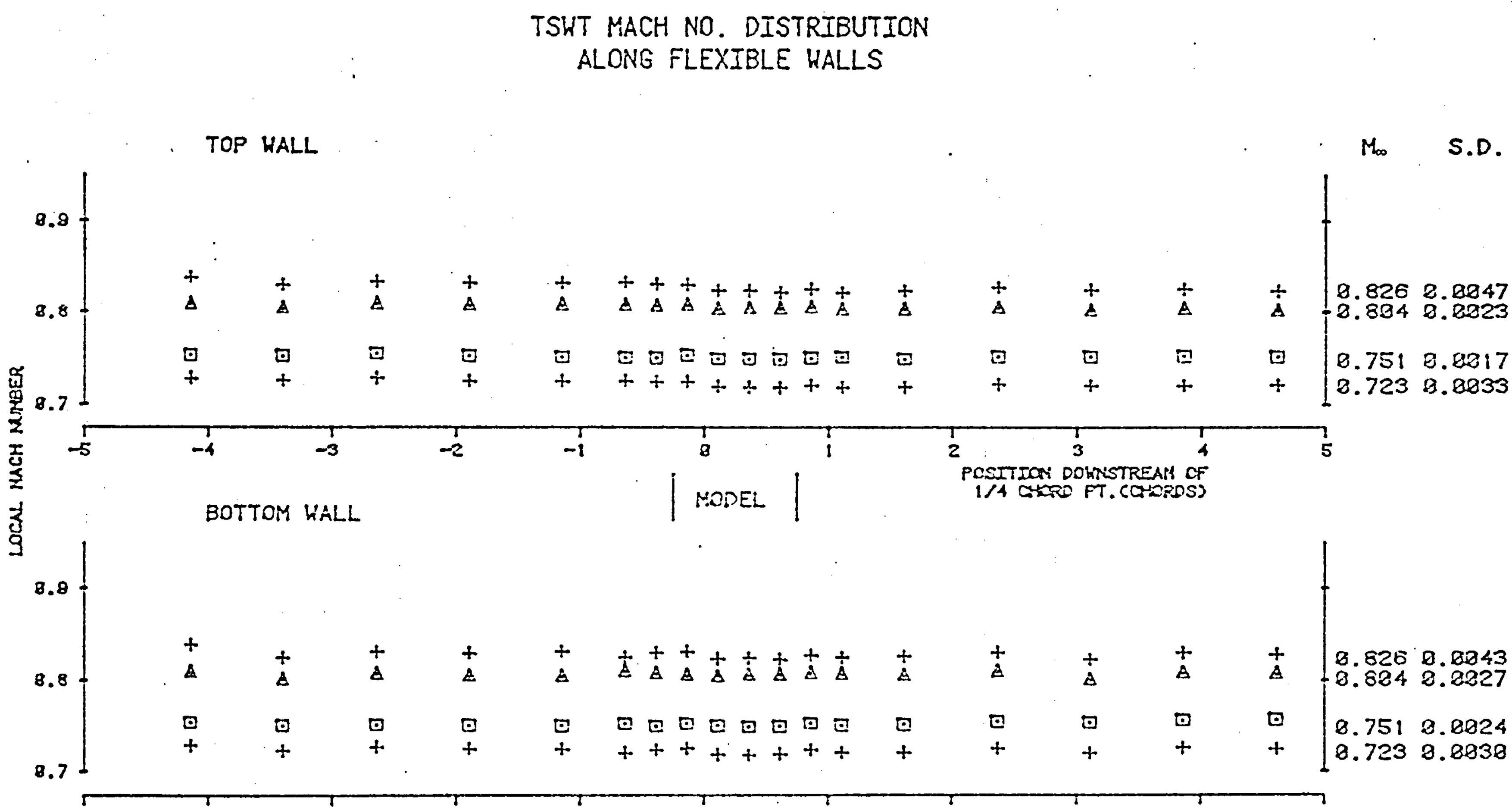

Fig 2.2 Test Section wall Mach number distributions, aerodynamically straight contours B

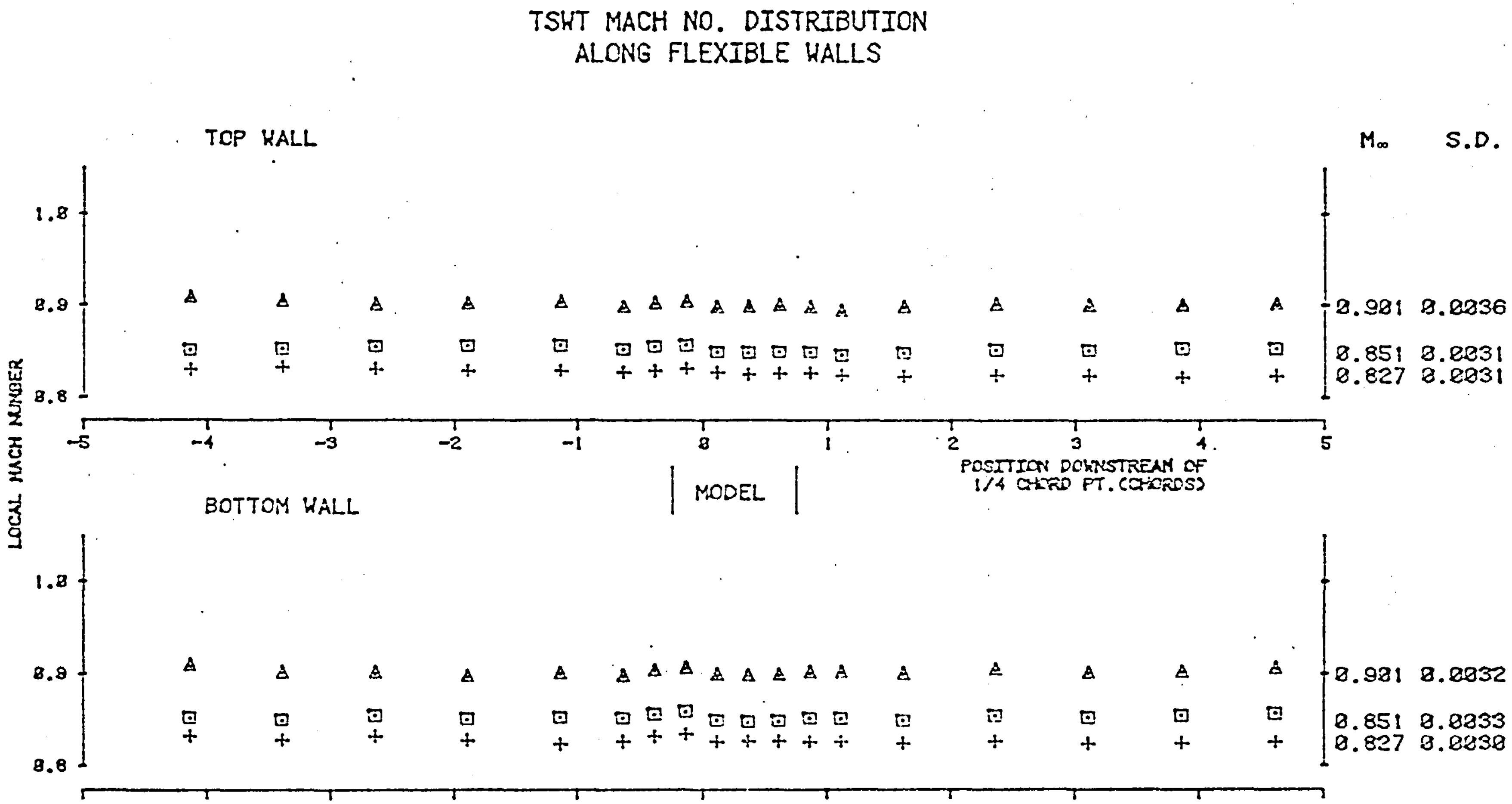

Fig 2.3. Test section wall Mach number distributions, aerodynamically straight contours C

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